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捕食性天敌储蓄植物系统研究进展与展望

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摘要：现代集约化农业生产对生态环境的影响逐渐加剧，促使形成单一化农业景观、丧失生物多样性，易引起害虫大暴发。随着我国现代农业发展战略布局与要求，对农业绿色安全生产和食品环境安全的关注度日益增加，环境友好、绿色高效的害虫管理技术的需求越来越强烈。天敌昆虫作为生物防治的重要组成部分，在生态安全和可持续农业中发挥着重要的作用。但传统的淹没式释放天敌的方式存在成本高、时效性和持效性较差的问题。如何有效的增殖保护田间天敌昆虫，提高天敌控害效率一直是生物防治的关键。储蓄植物系统（banker plant system）又称载体植物系统，其具有预防性引入天敌、并有助于天敌种群维持，实现可持续控害等优点，是较为成功的保护型生物防治技术，被越来越多用于农业有害生物综合治理中改善天敌生存条件，发挥对其的涵养和增殖作用。近年来相关研究发展迅速，在比利时、德国、法国、日本、美国和加拿大等国家已形成了商品产业化，得到了广泛推广应用。但由于地理气候和农业设施等方面差异，国外已报道或构建的储蓄植物系统并不适于直接在我国应用。目前国内的研究虽然起步较晚，但已到了快速发展期，必将具有广阔的发展前景。本文综合分析了国内外相关技术研究概况，就实现捕食性天敌储蓄植物系统最佳控害功能进行探讨，提出要认真筛选组成因素，明确储蓄植物、替代食物和有益生物三者之间的关系并优化各个因素的水平，而且还要充分考虑应用策略，重视田间应用效果评价，从而进一步完善储蓄植物系统技术。此外，还展望了该领域的发展方向，因地制宜地开发适合国内害虫防治的捕食性天敌储蓄植物系统，必将推动捕食性天敌产品的广泛应用及产业化发展。

关键词：储蓄植物；捕食性天敌；替代食物；保护型生物防治；设施害虫防治

Research Progress and Prospect on Banker Plant Systems of Predators for Biological Control

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Abstract: The impact of intensive agriculture on the ecological environment is growing, which fosters singular landscape, loss of biodiversity and prone to pest outbreaks. With the national development strategy of modern agriculture, much attention has been paid to the production of healthy, sustainably grown food. The requirement for environmentally friendly and efficient pest management technologies has become more and more intensified. Natural enemies play an important role in ecological security and sustainable agriculture. However, the traditional method of mass releasing natural enemies has the problems of high cost, poor timeliness and efficiency. So how to protect natural enemies in the field and improve efficiency are the critical problems to successful biological control. Banker plant systems have the advantages of introducing natural enemies preventively and maintaining them, therefore, controlling the pests sustainably. It is a relatively successful protective biological control technology, which has improved

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the survival conditions of natural enemies in the comprehensive management of agricultural pests. In recent years, with the rapid development of banker plant systems, more and more products have been widely applied in Belgium, Germany, France, Japan, the United States, Canada, and so on. However, due to the geographical differences, the direct application of the banker plant systems reported abroad is difficult in most cases. At present, although the domestic study started late, it has reached a rapid development period and will have a broad development prospect. In this paper, the research progress and the related technology in China and abroad were summarized. Especially, the optimal strategy of predatory natural enemies was discussed in banker plant system. The improvement of the technology not only needs careful selection of the factors, but also clarifies the relationship and optimizes the levels of the elements. Moreover, fully considering is in the layout of space and time, especially the application effect evaluation in the field. That will improve the banker plant system technology. And the prospect of the development direction in the future was pointed out. Based on principles of adjusting measures to local conditions, the advanced banker plant system would surely promote the widespread application and industrialization of predatory natural enemy products.

Key words: banker plant; predator; alternative food; conservation biological control; greenhouse pest control

天敌昆虫是农业生态系统重要的控害因素，在农作物害虫防治中起着重要的作用。近年来新兴的保护型生物防治技术利用生态调控技术来改善天敌生存条件，同时提高了生物多样性，被越来越多的应用在农业有害生物综合治理中[1-3]。基于景观复杂性假说、联合抗性假说、资源集中假说等害虫生态调控理论，多角度解释了利用有益植物进行生境调控，可以有效提升天敌定殖率及持续控害能力[4]。这些有益植物为天敌提供食物、越冬和繁殖栖境，帮助天敌躲避农药和耕作干扰。按照对天敌的作用和功能，可分为储蓄植物（banker plant）、蜜源植物（nectar resource plant）、栖境植物（habitat plant）、诱集植物（trap plant）、指示植物（indicator plant）和护卫植物（guardian plant）等[5-6]。目前研究较多的是储蓄植物，又称载体植物或开放式天敌饲养系统[7]，能够支持天敌在系统中“预存”与“增殖”[6,8]，此系统已在比利时、德国、法国、日本、美国和加拿大等国家的温室及大田作物有害生物防治中推广应用[3,9-14]。

捕食性天敌大多成虫或幼虫阶段均可捕食，普遍具有捕食量大及环境适应性强等优点[15-17]。尽管许多研究表明捕食性天敌具有显著的控害效果[18-20]，但需要多次、大量释放，这不仅增加了防治成本，而且也可能会引起潜在生态风险[9,21-22]。而储蓄植物系统可以预防性地将天敌引入作物中，在作物全生育期中有助于捕食性天敌维持种群[7]，从而达到可持续控害效果，减少了天敌释放并降低了生态风险。此外，还可以吸引一些本地其他天敌定殖，从而提高害虫的综合防治效果[23]。如 PINEDA 等[24]在甜椒温室中使用黑带食蚜蝇（*Episyrphus balteatus*）储蓄植物系统时发现，此系统还可吸引内宽尾细腹蚜蝇（*Sphaerophoria rueppellii*），使其数量增加提高生防效果。由于田间常存在多种害虫混合发生的情况，广食性或适应性相对较强的捕食性天敌更具生防潜力。因此，捕食性天敌储蓄植物系统成为保护型生物防治技术重要的研究方向，具有广阔的发展前景。

本文以捕食性天敌储蓄植物系统为主线，从储蓄植物系统技术发展、主要构建要素等方面对近年来国内外的相关研究进展等进行了综述，并提出了捕食性储蓄植物系统应用策略，为捕食性天敌储蓄植物系统的应用理论与技术的进一步研究提供参考。

1 储蓄植物系统研究与应用概况

1970 年，捷克科学家 STARÝ 使用“artificial foci”首次提出了储蓄植物的理念，利用芸苔属（*Brassica*）植物繁殖甘蓝蚜（*Brevicoryne brassicae*）饲养菜少脉蚜茧蜂（*Diaeretiella rapae*）以防治温室中桃蚜（*Myzus persicae*）[25]。PARR 等研究应用丽蚜小蜂（*Encarsia formosa*）的储蓄植物系统，防治危害番茄的温室白粉虱（*Trialeurodes vaporariorum*），发现丽蚜小蜂在系统中可维持 8 周[26-27]。第一例成功的捕食性天敌储蓄植物系统是由丹麦科学家 HANSEN[28]提出并建立，以蚕豆（*Vicia faba*）为储蓄植物支持食蚜瘿蚊（*Aphidoletes aphidimyza*）防治温室辣椒（*Capsicum annuum*）上的桃蚜，达到与化学农药防治相同的效果。21 世纪初，储蓄植物系统产品已开始在欧美商品化[7]，如 XIAO 等[29]建立的玉米（*Zea mays*）-草地小爪螨（*Oligonychus pratensis*）-食螨瘿蚊（*Feltiella acarisuga*）储蓄植物系统，实现对二斑叶螨（*Tetranychus urticae*）的防控，并在美国的番茄（*Solanum lycopersicum*）、黄瓜（*Cucumis sativus*）、茄子（*Solanum melongena*）等设施作物生产中得到推广应用。目前，国际知名生防公司 Koppert、Biobest

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等在比利时、芬兰、法国、德国、匈牙利、意大利、荷兰、波兰、俄罗斯、西班牙、英国等国家均有储蓄植物系统商品化销售应用，如小麦（*Triticum aestivum*）-麦长管蚜（*Sitobion avenae*）-阿尔蚜茧蜂（*Aphidius ervi*）、小麦-禾谷缢管蚜（*Rhopalosiphum padi*）-粗脊蚜茧蜂（*Aphidius colemani*）等。此外，用观赏性辣椒、罗勒（*Ocimum basilicum*）构建的小花蝽（*Orius* spp.）储蓄植物系统在比利时、加拿大、澳大利亚等也有商业推广应用[7]。近年来，我国也开始研发捕食性天敌储蓄植物系统工作，例如小麦-玉米蚜（*Rhopalosiphum maidis*）-龟纹瓢虫（*Propylaea japonica*）[16]和玉米-禾谷缢管蚜-异色瓢虫（*Harmonia axyridis*）（待发表）等，部分已用于温室蔬菜上蚜虫的防治。

自 1970 年至今，国内外对于储蓄植物系统的研究论文已发表近 150 余篇。尽管 HANSEN[28]建立的第一例捕食性天敌储蓄植物系统比 PARR 等[26]提出的第一例寄生性天敌的储蓄植物系统迟了 7 年，但自 21 世纪以来，捕食性天敌储蓄植物系统研究发展迅速，这可能与越来越多的捕食性天敌大规模应用有关。但目前仅有少量捕食性天敌储蓄植物系统用于大田害虫防治，如防治水稻上的褐飞虱（*Nilaparvata lugens*）[30]，其余大部分用于防治温室害虫（表 1—表 3），其中关于蚜虫防治有 13 篇，主要是用于防治棉蚜（*Aphis gossypii*）与桃蚜（表 1）；其次是粉虱防治有 10 篇（表 2）。已发表文章中研究最多的捕食性天敌为食蚜瘿蚊、斯氏钝绥螨（*Amblyseius swirskii*）以及一些捕食性盲蝽。

2 捕食性天敌储蓄植物系统的构建要素

储蓄植物系统一般包含储蓄植物、替代食物（alternative food）和有益生物（beneficial）3 个基本要素，本文中有益生物主要围绕捕食性天敌（图 1）。构建优良的捕食性天敌储蓄植物系统需要认真筛选各要素，三者之间关系的平衡也决定了这种天敌系统的防治效果。

表 1 用于温室内蚜虫防治的主要捕食性天敌储蓄植物系统

Table 1 List of main banker plant systems of predatory beneficial against aphids in greenhouse

靶标害虫 Target pest	储蓄植物 Banker plant	替代食物 Alternative food	捕食性天敌 Predator natural enemy	目标作物 Crop	参考文献 Reference
桃蚜 *Myzus persicae*	蚕豆 *Vicia faba*	巢菜修尾蚜 *Megoura viciae*	食蚜瘿蚊 *Aphidoletes aphidimyza*	辣椒 *Capsicum annuum*	文献[28] Reference [28]
	燕麦 *Avena sativa*	麦无网长管蚜 *Metopolophium dirhodum*	食蚜瘿蚊 *Aphidoletes aphidimyza*	辣椒 *Capsicum annuum*	文献[31] Reference [31]
	大麦 *Hordeum vulgare*	玉米蚜 *Rhopalosiphum maidis*	黑带食蚜蝇 *Episyrphus balteatus*	辣椒 *Capsicum annuum*	文献[24] Reference [24]
	小麦 *Triticum aestivum*	玉米蚜 *Rhopalosiphum maidis*	龟纹瓢虫 *Propylaea japonica*	未报道 Not reported	文献[16] Reference [16]
	蚕豆 *Vicia faba*	豌豆修尾蚜 *Megoura japonica*	七星瓢虫 *Coccinella septempunctata*	未报道 Not reported	待发表 Unpublished
棉蚜 *Aphis gossypii*	小麦 *Triticum aestivum*	禾谷缢管蚜 *Rhopalosiphum padi*	普通草蛉 *Chrysopa carnea*	黄瓜 *Cucumis sativus*	文献[32-33] Reference [32-33]
	大麦 *Hordeum vulgare*	麦二叉蚜 *Schizaphis graminum*	食蚜瘿蚊 *Aphidoletes aphidimyza*	甜瓜 Oriental melon	文献[34-35] Reference [34-35]
				茄子 *Solanum melongena*	文献[36-37] Reference [36-37]
	高粱 *Sorghum bicolor*	高粱蚜 *Melanaphis sacchari*	食蚜瘿蚊 *Aphidoletes aphidimyza*	辣椒 *Capsicum annuum* 茄子 *Solanum melongena*	文献[37-38] Reference [37-38]
	牛筋草 *Eleusine indica*	狗尾草蚜 *Hysteroneura setariae*	狭臀瓢虫 *Coccinella transversalis* 六斑月瓢虫 *Menochilus sexmaculatus*	蔬菜 Vegetable	文献[39] Reference [39]
茄沟无网蚜 *Aulacorthum solani* 李短尾蚜 *Brachycaudus helichrysi*	大麦 *Hordeum vulgare*	禾谷缢管蚜 *Rhopalosiphum padi*	食蚜瘿蚊 *Aphidoletes aphidimyza*	菊 Chrysanthemums	文献[40] Reference [40]

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表 2 用于温室内粉虱防治的主要捕食性天敌储蓄植物系统

Table 2 List of main banker plant systems of predatory beneficial against whiteflies in greenhouse

靶标害虫 Target pest	储蓄植物 Banker plant	替代食物 Alternative food	捕食性天敌 Predator natural enemy	目标作物 Crop	参考文献 Reference
烟粉虱	木瓜	木瓜粉虱	小黑瓢虫	蔬菜	文献[41]
Bemisia tabaci	*Carica papaya*	*Trialeurodes variabilis*	*Delphastus pusillus*	Vegetable	Reference [41]
	美女樱	未报道	烟盲蝽	番茄	文献[42]
	Verbena hybrida	Not reported	*Nesidiocoris tenuis*	*Solanum lycopersicum*	Reference [42]
	辣椒	花粉	斯氏钝绥螨	绿豆	文献[11]
	Capsicum annuum	Pollen	*Amblyseius swirskii*	*Vigna radiata*	Reference [11]
温室白粉虱	烟草	地中海粉斑螟卵	黑暗长脊盲蝽	番茄	文献[43]
Trialeurodes	*Nicotiana tabacum*	*Ephestia kuehniella*	*Macrolophus caliginosus*	*Solanum lycopersicum*	Reference [43]
vaporariorum	欧洲稻槎菜	欧洲甘蓝粉虱	黑暗长脊盲蝽	黄瓜	文献[44]
	Lapsana communis	*Aleyrodes proletella*	*Macrolophus caliginosus*	*Cucumis sativus*	Reference [44]
	毛蕊花 *Verbascum thapsus*	植物汁液 Sap	西方猎盲蝽	番茄	文献[45-47]
	辣椒 *Capsicum annuum*	粉斑螟卵 *Ephestia*	*Dicyphus hesperus*	*Solanum lycopersicum*	Reference [45-47]
	茄子 *Solanum melongena*				
	罗勒 *Ocimum basilicum*	花粉或叶	矮小长脊盲蝽	番茄	文献[48-49]
	烟草 *Nicotiana tabacum*	Pollen or leaf	*Macrolophus pygmaeus*	*Solanum lycopersicum*	Reference [48-49]

表 3 用于温室内蓟马、叶螨和其他害虫防治的主要捕食性天敌储蓄植物系统

Table 3 List of main banker plant systems of predatory beneficial against thrips, mites, and other pests in greenhouse

靶标害虫 Target pest	储蓄植物 Banker plant	替代食物 Alternative food	捕食性天敌 Predator natural enemy	目标作物 Crop	参考文献 Reference
二斑叶螨	香柏 *Thuja occidentalis*	针叶小爪螨	伪新小绥螨	景观苗圃 Commercial	文献[50]
Tetranychus urticae	杜鹃 *Rhododendron* sp.	*Oligonychus ununguis*	*Neoseiulus fallacis*	landscape plant	Reference [50]
	玉米	草地小爪螨	捕螨瘿蚊	未报道	文献[29]
	Zea mays	*Oligonychus pratensis*	*Feltiella acarisuga*	Not reported	Reference [29]
	河岸葡萄 *Vitis riparia*	阿勒颇松花粉	加州新小绥螨	玫瑰	文献[51]
	地中海荚迷 *Viburnum tinus*	*Pinus halepensis*	*Neoseiulus californicus*	*Rose sonia*	Reference [51]
	玫瑰 *Rosa sonia*	花粉	加州新小绥螨	菜豆	文献[52]
	地中海荚蒾 *Viburnum tinus*	Pollen	*Neoseiulus californicus*	*Phaseolus vulgaris*	Reference [52]
侧多食跗线螨	观赏性辣椒	未报道	斯氏钝绥螨	辣椒	文献[53]
Polyphagotarsonemus latus	*Capiscum annuum*	Not reported	*Amblyseius swirskii*	*Capsicum annuum*	Reference [53]
叶螨	蓖麻	花粉	伊绥螨	辣椒	文献[54]
Leaf mite	*Ricinus communis*	Pollen	*Ipheseius degenerans*	*Capsicum annuum*	Reference [54]
蓟马				黄瓜	文献[55]
Thirp				*Cucumis sativus*	Reference [55]
西花蓟马	金盏花	花蜜	东亚小花蝽	番茄	文献[56]
Frankliniella occidentalis	*Calendula officinalis*	Extrafloral	*Orius sauteri*	*Solanum lycopersicum*	Reference [56]
	孔雀草 *Tagetes patula*	未报道	狡小花蝽	观赏作物	文献[57]
	蓖麻 *Ricinus communis*	Not reported	*Orius insidiosus*	Ornamental crop	Reference [57]
	观赏性辣椒 *Capsicum annuum*				
	非洲菊 *Gerbera jamesonii*				
	小白菊 *Tanacetum parthenium*				
	向日葵 *Helianthus annuus*				
西花蓟马	蓖麻 *Ricinus communis*	土耳其松花粉	斯氏钝绥螨	辣椒 *Capsicum annuum*	文献[11]
Frankliniella occidentalis	观赏性辣椒	Pollen of *Pinus brutia*	*Amblyseius swirskii*	黄瓜 *Cucumis sativus*	Reference [11]
小黄蓟马	*Capiscum annuum*			绿豆	文献[58-59]
Scirtothrips dorsalis				*Vigna radiata*	Reference [58-59]
				观赏植物	文献[60]
				Ornamental plant	Reference [60]
	观赏性辣椒	花粉	狡小花蝽	观赏草	文献[61-62]
	Capiscum annuum	Pollen	*Orius insidiosus*	Ornamental grass	Reference [61-62]
蓟马	辣椒	花粉	斯氏钝绥螨	未报道	文献[63]
Thirp	*Capsicum annuum*	Pollen	*Amblyseius swirskii*	Not reported	Reference [63]
番茄潜叶蛾	芝麻 *Sesamum indicum*	未报道	烟盲蝽	番茄	文献[64]
Tuta absoluta	黏性旋复花 *Dittrichia viscosa*	Not reported	*Nesidiocoris tenuis*	*Solanum lycopersicum*	Reference [64]

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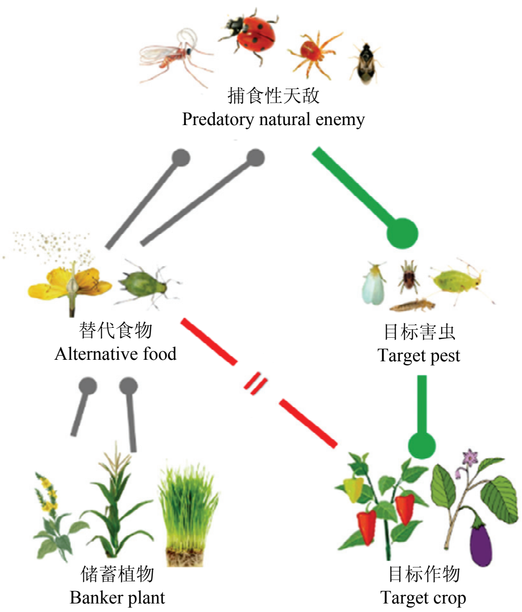

箭头线段粗细和端点大小指代各营养级关系强弱；储蓄植物提供花粉或替代猎物的寄主，直接或间接为捕食性天敌提供有限的替代食物，从而维持和增殖其种群；在目标害虫出现时，天敌控制其种群，从而减轻其对目标作物的危害，达到生物防治目标 Level of interaction among trophic levels shown by thickness of arrows and size of circular endpoints. Banker plant provides nutrition, such as pollen, or host for alternative prey, to support the predatory natural enemy ahead of the preys' arrival. When the target prey is destructive to crop, the predator could control them to some extent

图 1　捕食性天敌储蓄植物系统防治害虫模式图

Fig. 1　A model of banker plant system of predators for biological control of arthropod pests

2.1　储蓄植物

储蓄植物是指可以为系统中的捕食性天敌直接提供替代食物（如花粉、花外蜜）或间接繁殖替代猎物的植物[13]。筛选出优质的储蓄植物是建立高效的储蓄植物系统的基础。

在储蓄植物系统研究发展初期，储蓄植物多与目标作物相同[27-28,65]，这可能受到当时主流的生防策略"害虫优先（pest-in-first）"影响。储蓄植物与目标作物一致，可避免不同品种或物种之间不可预测的相互作用[66]，减少额外种植储蓄植物，方便管理，且可与目标作物一起收获[28]，但这样会导致替代猎物危害目标作物。随后的生产实践中，人们考虑使用非目标作物的植物和不危害目标作物的节肢动物来增加天敌定殖的机会，以降低目标作物受危害的概率，逐渐推动了储蓄植物系统的形成和发展[6,13,31]。RAMAKERS[67]提出了"捕食者优先（predator-in-first）"的生物防治策略，在害虫发生前，利用捕食性天敌在植物上生存和繁殖的特性，达到预防害虫发生危害的目的。储蓄植物不但自身营养物质（如花粉、花外蜜）可以直接涵养捕食性天敌；也可提供替代猎物，间接为捕食性天敌提供食物支持[13]，进一步拓展了"捕食者优先"的策略。目前较为成功的有单子叶储蓄植物，如小麦、大麦（*Hordeum vulgare*）、高粱（*Sorghum bicolor*）、玉米等和双子叶植物如烟草（*Nicotiana tabacum*）、蓖麻（*Ricinus communis*）、毛蕊花（*Verbascum thapsus*）、蚕豆等（表 1—表 3）。

优良的储蓄植物需要有利于替代猎物增殖。具有抗虫性或营养不适合的储蓄植物会影响替代猎物的发育和繁殖[68]，可能间接影响天敌的发育历期、寿命和死亡率[66]。储蓄植物的不同品种由于抗性等差异也会影响替代猎物的增殖[69]，因此需要评价替代猎物在不同品种储蓄植物上的增殖能力，筛选出合适的储蓄植物品种。而选用自身营养物质就能提供食物给天敌种群繁殖的储蓄植物避免了筛选替代猎物的麻烦。如使用毛蕊花和芝麻（*Sesamum indicum*）为捕食性盲蝽提供食物[45,64]、观赏性辣椒为捕食螨和小花蝽提供食物[11,61]等。LI 等[70]研究发现油菜（*Brassica campestris*）与玉米的花粉能够吸引龟纹瓢虫和东亚小花蝽（*Orius sauteri*），还能为储蓄目标天敌外的其他天敌提供营养源。GOLEVA 等[71]试验发现玉米、蓖麻花粉可作为储蓄植物为斯氏钝绥螨提供良好的营养支持。在替代食物或猎物确定的情况下，测定捕食性天敌在该植物上的适合度也是非常必要的[72]。选用自身营养物质有益于天敌种群繁殖的储蓄植物，对天敌生长发育的影响在不同品种间差异不大[11,60]。如 KUMAR 等[73]发现作为储蓄植物的观赏性辣椒的 4 个品种之间，对斯氏钝绥螨的发育历期、成虫寿命和繁殖力等的影响均无显著差异。

最后，还需要考虑储蓄植物的种植及维护。根据应用环境（温室或大田等）的不同需要，选择适宜本地的、易于繁育、生长周期长的植物种类，这样就不用频繁更换储蓄植物，从而降低成本。如 JACOBSON 等[74]就比较了小麦、黑麦和玉米这 3 种作物被用作储蓄植物的潜能，发现在同样被替代猎物取食的条件下，玉米可以在温室中维持 3 个月并且仅需要补充一次替代食物，而小麦和黑麦仅为 3—4 周。当然，也可以考虑选择能有额外收获的作物作为储蓄植物。例如，NGUYEN-DANG 等[47]发现茄子不仅作为储蓄植物使西方猎盲蝽（*Dicyphus hesperus*）种群增长，还可以收获其果实，实现防控害虫与增加产值的双赢。

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此外，储蓄植物的耐受性也需要着重考虑，例如，如果具有不易受非靶标病虫害侵染的特点，将延长整个系统的使用寿命从而增强天敌的防控效果[13]。再如，选择耐高温的储蓄植物将有利于在夏季温室中使用[23,35]。同时，也需评价储蓄植物的营养物质对靶标害虫的作用，以避免其受益而扩繁，导致害虫再猖獗[75]。

2.2 替代食物或猎物

替代食物一般是植食性节肢动物、储蓄植物的营养物质（如花粉）以及灭活鳞翅目昆虫的卵[43]等。如果使用与靶标害虫相同或近似的物种，就有可能会对目标作物等造成危害[28]。因此，储蓄植物系统中最常使用的替代食物为自身的营养物质（如花粉）或只取食储蓄植物的植食性节肢动物，以避免目标作物受到危害风险。

天敌对替代食物的取食偏好是评价储蓄植物系统的重要环节[29,76]。选择替代食物或猎物时，首先要考虑其是否适合天敌的生长、繁殖与发育[77]。若替代食物或猎物影响捕食性天敌的取食、寄生或产卵偏好，必将会降低对作物中害虫的防治效果。

其次，必须注意选择的替代猎物不能危害目标作物。当使用与目标害虫相同或近似的物种，就会对目标作物造成危害[27]。最好选择严格的单食性或寡食性的本地种节肢动物作为替代猎物，因为外来物种可能对环境产生潜在危害[13]。当然，一些植食性昆虫尽管是农业害虫，在不危害目标作物的前提下，仍然可利用其作为替代猎物，如危害小麦的禾谷缢管蚜、危害白菜的甘蓝粉虱（*Aleyrodes proletella*）[13,78]。目前文献报道中最常用的替代猎物依次为禾谷缢管蚜、麦长管蚜、玉米蚜、木瓜粉虱（*Trialeurodes variabilis*）等（表1、表2）。

最后，还应注意替代猎物的种群数量，在储蓄植物上维持有限的替代猎物可能会促使天敌向目标作物扩散[13,50]。反之，捕食性天敌专注取食替代猎物，可能会降低了对靶标害虫的控害作用。

2.3 捕食性天敌

捕食性天敌必须既可以捕食靶标害虫也可以取食替代食物或猎物，并能正常生长和繁殖[13]。捕食性天敌对靶标害虫和替代食物的偏好性也是需要考量的，如果偏好取食替代食物，则会降低其对靶标害虫的控制能力。HIGASHIDA 等[36]通过实验室及温室笼罩试验表明，食蚜瘿蚊在带有棉蚜的目标作物上产卵多于在储蓄植物大麦上，这对于可持续控害效果的发挥是十分有利的。捕食性天敌最好具有一定的扩散能力，其将决定整个储蓄植物系统的控害作用范围，扩散能力较强的天敌，可以减少应用点数，降低成本。

如果能建立多种天敌共存的储蓄植物系统，就可以同时对靶标害虫和其他多种害虫进行控制。当然，多种天敌的种间竞争和相互捕食可能会降低防治效果[13,79]。POCHUBAY 等[80]研究表明，与应用1—2种天敌相比，当温室内黄瓜新小绥螨（*Neoseiulus cucumeris*）、剑毛帕厉螨（*Stratiolaelaps scimitus*）和隐翅虫（*Atheta coriaria*）3种天敌共存时，蓟马的种群水平反而显著增加。

3 捕食性天敌储蓄植物系统应用策略

要获得捕食性天敌储蓄植物系统的最佳服务功能，不仅要从内部组成上对各因素进行优化，而且需要从整体布局和使用时机上采取合理策略，以实现高效应用（图2）。

3.1 储蓄植物系统组成因素的筛选

FRANK[9]指出很多储蓄植物并没有经过认真的筛选，已经应用的也没有明确证据证明其最适性。陈学新等[6]也指出除了考虑系统本身的多级营养关系外，还要把目标作物及靶标害虫甚至近缘种都包括在内，从生态系统的角度充分理清各组成因素之间的相互作用，从而筛选出较为合适的储蓄植物系统。已有的研究初步证明了一些有益植物对天敌具有支持作用，如金盏菊（*Calendula officinalis*）伴存下的七星瓢虫（*Coccinella septempunctata*）种群个体数增长显著高于对照组[15]；田间蓝蓟（*Echium vulgare*）、芥菜（*Brassica juncea*）、硫华菊（*Cosmos sulphureus*）、荞麦（*Fagopyrum esculentum*）、紫花苜蓿（*Medicago sativa*）、红麻（*Hibiscus cannabinus*）、陆地棉（*Gossypium hirsutum*）上会存在大量小花蝽[81]，这些植物为构建储蓄植物系统奠定了基础，当然还需要评估其对目标作物及靶标害虫影响，才能充分发掘它们作为储蓄植物的潜力。

在构建储蓄植物系统选择各组成因素时，需要考虑其应用环境的影响，明确各因素适应环境的能力，才能精准定位应用范围。例如，由于夏季温室中高温持续时间较长，可选择喜温的冬小麦和大麦作为储蓄植物[82]。研究发现，当豌豆修尾蚜（*Megoura japonica*）作为替代猎物时，会因为不适应这种持续高温而产生种群消退。常用的寄生性天敌粗脊蚜茧蜂由于不能适应高温，在夏季温室内的防控效果就很低[83]。因此针

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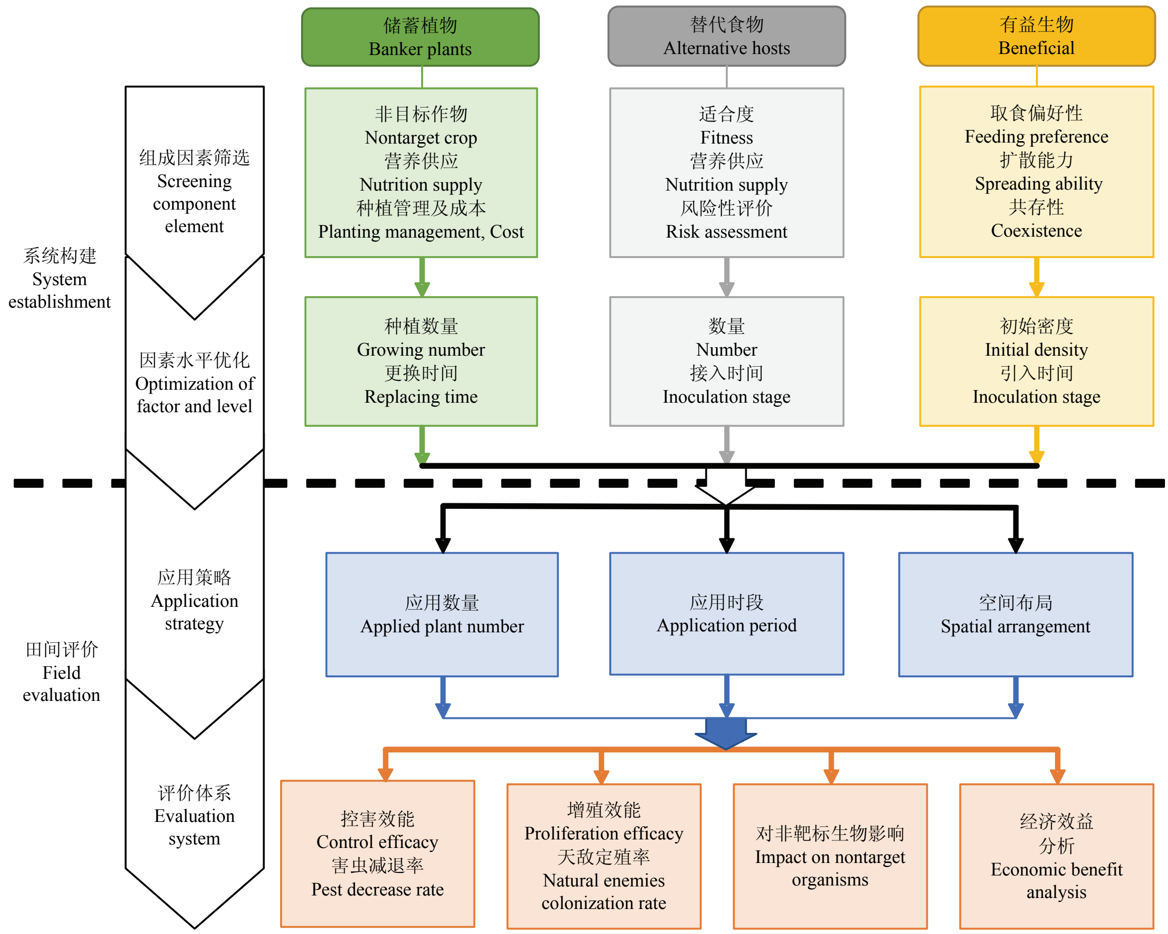

图 2　储蓄植物系统构建及应用模式流程图

Fig. 2　A model of banker plant system established for biological control

对储蓄植物系统适用温度不同，可以考虑多种系统分时段或时期使用。

此外，明晰农业生态系统中植物与节肢动物的相互作用，对于改善保护性生物防治的效果有重要意义[84]。对选用的储蓄植物、替代食物或猎物、天敌、目标作物及靶标害虫进行基础的生物学和生态学研究，明确它们之间的相互关系[85]，有助于筛选储蓄植物系统的各个组成因素。在进行评估替代猎物是否会危害目标作物的同时，也应关注储蓄植物的病害是否会危害目标作物。ORFANIDOU 等[86]就发现防治危害番茄上的温室白粉虱的储蓄植物——假龙头（*Dittrichia viscosa*），成为番茄侵染性褪绿病毒（TICV）的源库，因此这种植物就不适合作储蓄植物。

3.2　储蓄植物系统各因素水平的优化

目前许多研究更注重于储蓄植物系统的构建，而进一步优化各因素应用参数的报道较少[11,39,60]。邓从双等[16]使用正交试验法，探索了储蓄植物系统中替代猎物蚜虫的接种时间和接种密度，以及天敌（瓢虫幼虫）的投入时间和初孵幼虫的投入数量 4 种因素的不同水平对系统中瓢虫成虫获得量的影响，得到了最佳组合，从而优化了龟纹瓢虫储蓄植物系统。而储蓄植物系统的应用参数，如储蓄植物、替代食物或猎物和天敌初始密度以及整个系统更换周期等则需要更深入研究才能形成推广应用的技术规程。

3.3　储蓄植物系统的布局

储蓄植物系统能预防性控制作物上前期危害的少量害虫[9,35,87]。根据这一特点，再结合作物害虫发生规律及储蓄植物系统的使用寿命，来确定系统的引入时机。一般来说，在害虫危害前期引入储蓄植物系统，能够使其发挥预防害虫和增殖天敌的作用[6,35,87]。此外，也需要考虑储蓄植物的生长适应性和影响替代猎物的环境因子，如 JACOBSON 等[74]发现用玉米为储

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蓄植物的系统繁育的粗脊蚜茧蜂控制棉蚜的效果在仲夏要好于晚春。

在实际应用中储蓄植物系统的布局和密度等也会影响其防控效果[78,86]，而空间布局的设置往往与捕食性天敌的扩散能力有关。PRATT 等[50]提出，如果扩散能力较弱，可以通过增加密度的方法来提高防效。VAN DRIESCHE 等[78]证明布局的储蓄植物系统密度过低时，不能抑制温室中桃蚜暴发。

3.4 田间效果评价

控害效果评价是害虫生物防治措施推广应用的重要依据。在作物生产中如何评估天敌储蓄植物系统对靶标害虫的控制能力是非常重要的，因为如果不能将害虫控制到经济阈值之下是无法应用于实际生产中的[65]，这也是储蓄植物系统从实验室构建走向实际应用必经之路。如 WONG 等[61]使用观赏性辣椒作为储蓄植物支持狡小花蝽（*Orius insidiosus*）来防治生产苗圃中的蓟马，结果发现与直接释放小花蝽相比，未提高防治效果，推测开放式环境导致的小花蝽的迁出和外界蜘蛛的迁入影响了防治效果。因此需要通过综合考虑天敌产能、控害潜能、非靶标效应以及经济效益等各个方面，才可以较为准确的评估储蓄植物系统，并及时对系统进行修正和优化，以实现在生产中更好的控害效果，并顺利推广与应用。

储蓄植物系统应用效果的检验，通常是与多次释放天敌或化学防治措施相比较[88]。然而许多研究并没有足够的重复和对照，所以效果检验的不明确[27,35,46]。因此，在评价实际应用效果时，需要经过大量反复验证对照，发现存在的问题，不断优化储蓄植物系统技术参数。

4 结论与展望

欧美国家关于储蓄植物系统的研究较多，商品化的同时也得到了广泛推广和应用[3,89]。据统计，美国约有 1%—5%的温室在使用储蓄植物系统，加拿大约有 10%—25%，丹麦使用储蓄植物系统防治害虫的种植者比例则达 20%，在荷兰，用储蓄植物系统防治蚜虫面积约为 120 hm^2[7]。但是由于地理气候和农业设施等方面差异，国外已报道或构建的储蓄植物系统不适于在我国应用，亟需因地制宜地开发出适合国内农田环境的生防产品。目前，我国已发表的研究捕食性天敌储蓄植物系统的文章仅有 3 篇[16,30,56]，获得授权专利 1 项，实审中 1 项，而寄生性天敌的储蓄植物系统有 10 篇[12,69,90-97]，获得授权专利 3 项，实审中 4 项。可见捕食性天敌储蓄植物系统的研究还需进一步加强，特别是储蓄植物系统应用策略的研究和优化。

尽管有许多储蓄植物饲养天敌适合度、筛选饲养天敌的替代猎物的研究发表[85,98-99]，但鲜有全面考虑整个储蓄植物系统构建及田间优化应用方面的报道。从国外商品化的天敌产品类型及农户使用意愿调查发现，捕食性天敌因其食量大、控害种类多和环境适应性更强等，实际应用更多，因此开发构建捕食性天敌储蓄植物系统的发展空间是十分广阔的，而且有助于推动捕食性天敌产品的广泛应用及产业化发展。

针对作物生产中多种害虫种类混合发生的特点，未来不仅可以考虑构建多种天敌的储蓄植物系统[79]，还可以考虑与其他防治方法结合使用[2]。如 JAWORSKI 等[2]将金盏菊作为储蓄植物，与化学诱剂联用，对捕食性瓢虫种群有显著的诱集助增作用，可有效控制果园蚜虫种群。另外在害虫暴发需要化学防治时，可以将储蓄植物系统暂时移出，等农药安全期过后再放回[25]。或者应用对天敌安全的药剂及使用剂量[100-101]，从而实现储蓄植物系统与其他防治方法兼容。同时，储蓄植物系统还可以减少释放天敌的成本[7,13]，降低生防投入门槛，必将成为以生物防治为核心的现代绿色循环型植保体系重要技术之一。

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